# SPATIAL ACCESSIBILITY OF

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**Dept. of Agricultural Economics**

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**Abstract**

Healthy populations and access to health care services are significant factors influencing economic development and prosperity. Since geographic access is an essential feature of an overall health system, it is important for health service researchers to develop accurate measures of physical access to health. In this paper we develop a series of gravity-based health care accessibility measures for all the counties in Indiana. The measures go beyond local availability of health care services within a county and account for travel impedance via distance-discounted health care services accessible throughout the state. When applied to Indiana counties, the results show sharp disparities in health care accessibility with extensive pockets of poor accessibility in rural and peripheral areas. The research concludes with a demonstration of how spatial accessibility measures can be beneficially used to evaluate of policies indicative of changes in the provision of health services.

**Key words:** spatial accessibility, health care, geographic information systems (GIS), gravity model, Indiana

**JEL codes**: I12

## Introduction

The main goal of most public healthcare systems is to improve or achieve a healthier population. Physical Access to health services is one of the first steps in maintaining and improving population health. The provision of health services in the United States has not evolved solely in response to need. Instead, it has evolved as a result of a combination of factors such as government policies designed to promote provision of care (i.e. hospital services), profit motives on the behalf of private entities, and government programs designed to fund healthcare provision for the uninsured. Since these factors do not necessarily work together to ensure equitable distribution of healthcare services, it is vital for us to understand the existing geographical distribution of health services in relation to the populations they serve.

The main goal of health service delivery is to provide equitable utilization and access to health care services. An important factor in obtaining quality care is physical access to health care as lack of spatial access can result in delayed treatment and poor health outcomes. Fundamental to addressing the issues of equity and equitable access to health care is the issue of geographical distribution (Oliver and Mossialos 2004).

Accessibility to health care is a multidimensional concept and can be defined as the ability of a population to obtain health care services. It varies across space because neither health professionals nor residents are uniformly distributed (Lou and Wang 2003). Variations in spatial accessibility to health care are pronounced in many developing countries[1] but also persist in developed countries where medically underserved areas are often encountered in rural areas (Joseph and Bantock 1982, Fryer et al. 1999, Passik et al. 2002, Robst and Graham 2004). This paper thus focuses on the spatial dimension of health care accessibility and aims at identifying areas that are underserved or at risk of being underserved. Towards that goal, we apply gravity-based measures of spatial accessibility to health care professionals and facilities in Indiana. Visualizing the results allows us to provide a nuanced assessment of differential health care accessibility across space. Moreover, we use the results to identify the population segments most severely affected by poor spatial access to health care and demonstrate how the measures can be used to evaluate health service delivery and their impact on spatial accessibility.

The empirical analysis utilizes population data and data on health care facilities and physicians, geo-referenced at a sub-county spatial scale for the state of Indiana. Indiana is a Midwestern state sandwiched between Ohio in the East and Illinois in the West. Its population is unevenly distributed across 92 counties, with the largest county –Marion County– housing almost 14% of the state's 6.3 million residents. Indiana has a relatively large share of rural residents.[2] The evaluated health care policies thus focus on scenarios

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[1] See for example the studies by Perry and Gessler (2000) on Bolivia, Noor et al. (2003) on Kenya, Rosero-Bixby (2004) on Costa Rica, and Black et al. (2004) on Honduras.

[2] In 2000, the U.S. Census Bureau classified 29% of Indiana residents as rural, compared to only 21% of the U.S. population.

that potentially affect residents in rural areas, such as closures of rural health care facilities and consolidation of hospitals.

The remainder of this paper is organized as follows. In the next two sections the dimensions of health care access and measures of spatial accessibility, respectively, are discussed. They are followed by the empirical analysis, including separate subsections on the study area, data sources, the specification of gravity-based accessibility measure, the empirical results, and the evaluation of policy scenarios and their impacts on spatial accessibility of health care. Finally, the paper concludes with a summary and discussion of findings and future research directions.

## Access to Health Care

Spatial accessibility is a necessary, albeit not sufficient pre-requisite for equitable high-quality healthcare services for all population segments of society, whether they reside in urban agglomerations or in peripheral rural areas. However, spatial barriers—most notably long travel distances to health care facilities—are significant factors contributing to the exclusion from high-quality medical care.

| ACCESS DIMENSIONS | Spatial (Geographic) | Non-spatial (Social) |
| --- | --- | --- |
| Potential | Studies of distance and availability that do not consider utilization measures | Studies of affordability, culture and other non-spatial factors that do not consider utilization measures |
| Realized (Actual) | Utilization studies that consider spatial factors | Utilization studies that consider affordability, culture and other non-spatial factors |

**Figure 1:** A taxonomy of access, based on spatial/non-spatial dimensions and potential/realized stages
**Source**: Khan (1992) and Guagliardo (2004)

Khan (1992) and Guagliardo (2004) devised a useful scheme to categorize the wealth of literature on health care access into four groups, defined by potential versus realized/actual care and by spatial access versus social access (Figure 1). A common thread linking these studies are barriers to access. Penchansky and Thomas (1981) assigned these barriers to five dimensions: *affordability*, *accommodation*, *acceptability*, *availability* and *accessibility*. The first three are non-spatial in nature and have received extensive attention in the literature (see, for example, Lee and McKercher 2002, Matthews et al. 2006, Tarrier et al. 2006). They address health care financing arrangements and access barriers created by socio-economic and cultural factors (Guagliardo 2004). The final two dimensions—availability and accessibility—are spatial in nature. They address the adequacy of the supply of health care providers inside a region and travel impedance to health care providers outside the region, respectively.

Jointly, availability and accessibility are referred to as *spatial accessibility* (Guagliardo 2004, Luo and Wang 2003).

This study falls into the subset of studies dealing with potential spatial accessibility (upper-left hand quadrant in Figure 1). It builds on the literature focusing on geographic distances separating potential users from health care services, developing measures of spatial accessibility, and applying them to a multitude of spatial settings.

## Measuring Spatial Accessibility of Health Care

With the rise of new technologies for spatially referenced data, namely Geographic Information Systems (GIS), and advancements in the analysis of spatial data, health care research has focused more extensively on spatial accessibility (Bagheri et al 2006, Ebener et al. (2005), Luo and Wang 2003, Parker and Campbell 1998, Bazemore et al. 2003). While early applications of GIS in health care research focused on distribution and determinants of health and disease, more lately GIS has been applied to the planning and management of health care services (Parker and Campbell 1998). In this section, we briefly discuss the various measures of spatial accessibility

### *Provider-to-population ratios*

The provider-to-population ratio is the most simple measure of spatial health care accessibility and is defined as the ratio of health service capacity in the numerator (measured, e.g., as the number of physicians or the number of hospital beds) and population size in the denominator. It refers to a bounded area such as states, counties, or census districts and thus only addresses the supply or availability of health care services within that area. Three problems are typically encountered with the use of provider-to-population ratios. First, the delineation of the bounded area strongly influences the results as any change in the areal definition will change both the numerator and the denominator. Second, if the spatial units are small, e.g., zip codes or census districts, the population-to-provider ratios may be misleading as a measure of spatial accessibility because they ignore that the population can also utilize close-by health care services outside the bounded area. Third, if the areas are large such as metropolitan areas of states, then population-to-provider ratios are potentially misleading since they ignore internal variations of spatial accessibility, in particular differences between rural and urban areas. However, the provider-to-population ratio has the advantage of easy computation and only minimal data requirements. As such, it can be nicely used as a crude approximation of spatial accessibility. Moreover, it is particularly useful to track changes over time as geo-references in historical data are sparse.

Provider-to-population ratios have frequently been used in studies linking the supply of health care services to health outcomes (Waldorf et al. 2007). For example, Shi and Starfield (2001) focused on the effects of primary care physician supply—measured by the population-to-provider ratio—on mortality among Blacks and Whites across U.S. metropolitan areas in 1990. Provider-to-population ratios also take on a pivotal role in the delineation of Health Professional Shortage Areas (HPSAs) and Medically Underserved

Areas (MUA). HPSAs are defined by the U.S. Department of Health and Human Services (DHHS) using an elaborate system of threshold based criteria. For geographical areas,[3] DHHS defines an HPSA as an area –consisting of a group of counties, a county, or portions thereof– that meets one of the following conditions: (1) the ratio of residents to primary care physicians exceeds 3,500:1, whereby all primary care physicians within a distance of 30 minutes travel time are included; (2) the ratio of residents to primary care physicians is between 3000:1 and 3,500:1 and the area has unusually high needs for primary care services. Unusually high needs occur if there are more than 100 births per year per 1,000 women aged 15 – 44, if there is a high infant mortality (above 20 infant deaths per 1,000 live births, or if more than 20% of the population is poor; (3) primary medical care professionals in contiguous areas are overutilized, excessively distant, or inaccessible to the population of the area under consideration

***Travel impedance measures***

Unlike the provider-to-population ratios, travel impedance measures can be used when geo-referenced data for both patients and providers are available. For each patient $k$ and a set of providers $J$, travel impedance, $T_k$, is defined as a function of the costs that patient $k$ incurs when traveling to provider $j \in J$, $t_{kj}$ . Standard proxies for travel costs include travel time and various measures of travel distance, e.g., Euclidian distance or Manhattan distance. Two functional specifications yield easily interpretable measures, the minimum and the average.

Choosing the minimum function yields the travel impedance to the nearest provider:

$$T_k = \min_{j \in J} \quad t_{kj} \, .$$

Choosing the average function yields the average travel impedance to all providers in the system.

$$T_k = \frac{1}{J} \quad \sum_{j=1}^{J} t_{kj} \, .$$

While both measures are quite intuitive, they do not take the overall capacity into account. Moreover, the average is strongly influenced by outliers, that is, providers that are located far outside a patient's $k$ activity space. Despite these shortcomings, both the travel impedance to the nearest provider as well as the average travel impedance to providers are meaningful measures, in particular when comparing patients across vastly different spatial settings, e.g., rural, suburban, and innercity locations.

***Gravity measures***

Gravity measures respond to provider supply and travel impedance. Typically, they are applied to areal data but they can also be used for individual patient and/or provider data.

[3] DHHS designates different types of HPSAs for primary medical care, dental care, and mental health. These types refer to (a) geographical areas, (b) population groups, and (c) public or nonprofit medical facilities (see http://bhpr.hrsa.gov/shortage/hpsacritpcm.htm).

The underlying idea is to let the spatial accessibility at location $k$, $A_k$, account for the total service capacity of a set of providers, yet discount the service capacity offered at location $j$, $S_j$, by the travel impedance between locations $k$ and $j$. Thus:

$$A_k = \sum_{j=1}^{J} S_j f(t_{kj}),$$

where $f(t_{kj})$ is the discount function of travel impedance between locations $k$ and $j$. In most applications, the discount function is specified as an inverse function of distance, travel time or travel cost, with the parameter β indicating the strength of the discount.

$$f(t_{kj}) = t_{kj}^{-\beta}$$

Service capacity is often measured by the number of hospital beds or the number of physicians. In general, the discount parameter or distance decay parameter, β, depends on a variety of factors including patients' demographic and socio-economic attributes, available modes of transportation, and type of service (Lovett et al. 2002). For example, the travel impedance parameter for a 75-year old who does not have a driver license and seeks a routine check-up is probably much greater than for a 30-year old car owner going for an MRI. In practice, however, the specification of β, is often an *ad hoc* choice. In those circumstances, the gravity measures are best suited for comparative purposes rather than as a means to assess "true" spatial accessibility.

An important enhancement of the gravity model accounts for spatially varying demand (Joseph and Bantock 1982, Luo and Wang 2003). Clearly, without demand adjustment spatial accessibility in an urban area with many physicians will vastly exceed spatial accessibility in a rural area with just one physician. However, when accounting for the many more urban residents demanding services of the urban physicians, the rural-urban gap may diminish or even disappear. The demand adjusted specification of the gravity measures, takes on the form:

$$A_k = \sum_{j=1}^{J} S_j f(t_{kj}) / V_j,$$

where $V_j$ is the demand for services at location $j$. The demand comes from the population throughout the system. However, it can be reasonably assumed that the population's demand for services diminishes with increasing travel impedance. Thus, demand at $j$ is specified as:

$$V_j = \sum_{k=1}^{J} P_k f(t_{kj}).$$

***Small-scale measurements***

The availability of GIS and geo-referenced data at very fine spatial resolutions has led to a host of new attempts to measure spatial accessibility to health care (Parker and Campbell 1998, Philips et al. 2000, Rosero-Bixby 2004, Perry and Gessler 2004). WHO commissioned the development of *AccessMod*© that can be nicely used for health care policy assessments and management (see for example, Ebener et al. 2005, Black et al. 2004). These techniques are particularly useful in developing countries where data from administrative sources are often sparse. Thus, information layers typically extend beyond geo-referenced information on population and health care services but also include remotely-sensed data on land cover, road system and quality, and elevation, as well as extensive field work and ground-truthing using GPS (Perry and Gessler 2000). A less data intensive yet robust GIS method is the kernel density method. It defines continuous spatial accessibility surfaces taking into account supply of health care services and the sphere of influence of these services.

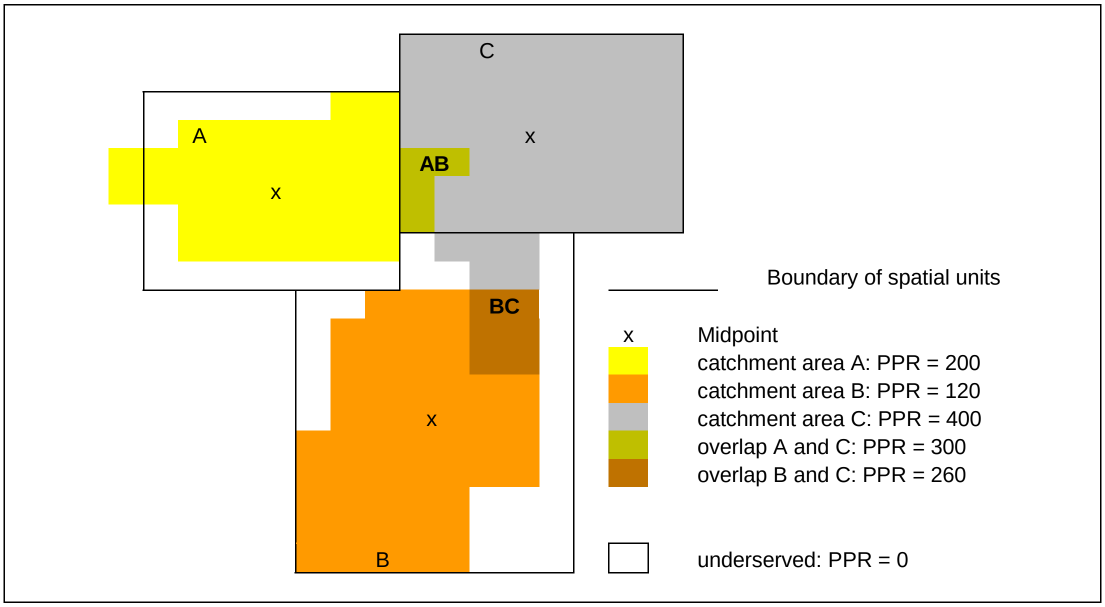


**Figure 2**: Example of three spatial units, their associated catchment areas centered about midpoints, and provider-to-population ratios (PPR) for different localities in the system.

To exemplify the power of GIS-based accessibility measures, the two-step floating catchment method (Bagheri et al. 2006) is described in more detail. The underlying algorithm begins with the calculation of provider-to-population ratios for each spatial unit, and subsequently centering a so-called catchment area on the midpoint of each spatial unit. The catchment area is defined by a travel impedance criterion, such as a circle of radius *r*, or an irregularly shaped polygon that includes all locations with less than travel time *t* to the midpoint. Furthermore, it is assigned the provider-to-population ratio of the associated spatial unit. A spatial location *k* thus may not fall into any catchment area, or into one or more catchment areas. Spatial accessibility for a location *k* is then defined as the average of the provider-to-population ratios of the associated catchment areas, or as zero if location *k* is not part of any catchment area (Figure 2).

The floating catchment method and other GIS-based methods have the advantage of not being confined to administrative boundaries and implicitly recognizing that patients cross borders to obtain medical services. Thus, Luo (2004) suggests that the method be used for the delineation of shortage areas and recommends a small spatial scale that can capture the broad variation of provider-to-population ratios. However, while the non-adherence to administrative borders allows greater flexibility, it should be recognized that this flexibility is based on an *a priori* and often *ad hoc* specification of travel impedance (e.g., 30 minute travel time or less than 20 miles). Moreover, the non-adherence to administrative boundaries makes it difficult to match catchment areas with published information on health, demographic, social and economic indicators. Thus, studies of the aggregate relationship between health care accessibility and health outcomes will not easily be able to derive the proper health outcome statistics for floating catchment areas.

## Empirical Analysis

### *Study Area*

Indiana is a Midwestern state with a long tradition in both agriculture and manufacturing. Not surprisingly, thus, almost a third (29.2%) of Indiana's 6.3 million residents live in rural areas, compared to only 21% in the nation. Indiana's urban system follows a typical hierarchy with its centrally located capital city, Indianapolis, accounting for more than 10% of the total population. Indianapolis is complemented by a series of smaller regional centers that are almost uniformly distributed across the state. An anomaly to this almost perfect Christallerian city system is the northwestern region of the state. This region is part of the tri-state Chicago consolidated metropolitan area, houses a very urban population and its economic base is comprised of the typical rustbelt industries.

**Table 1**. Physicians and Nurses per 100,000 Residents in 2004, Selected U.S. States

| **Rank** | **State** | **Physicians** per 100,000 residents | **Rank** | **State** | **Nurses** per 100,000 residents |
|---|---|---|---|---|---|
| | | **Top Three** | | | |
| 1 | Massachusetts | 450 | 1 | South Dakota | 1,207 |
| 2 | Maryland | 411 | 2 | North Dakota | 1,179 |
| 3 | New York | 389 | 3 | Massachusetts | 1,177 |
| | | **Midwestern States** | | | |
| 10 | Minnesota | 281 | 5 | Iowa | 1,107 |
| 11 | Illinois | 272 | 13 | Minnesota | 1,018 |
| 18 | Ohio | 261 | 14 | Missouri | 997 |
| 22 | Wisconsin | 254 | 15 | Ohio | 985 |
| 27 | Michigan | 240 | 16 | Wisconsin | 939 |
| 29 | Missouri | 239 | 23 | Illinois | 895 |
| **39** | **Indiana** | **213** | **25** | **Indiana** | **877** |
| 46 | Iowa | 187 | 29 | Michigan | 841 |
| | | **Bottom Three** | | | |
| 48 | Mississippi | 181 | 48 | Idaho | 631 |
| 49 | Oklahoma | 171 | 49 | Nevada | 604 |
| 50 | Idaho | 169 | 50 | California | 590 |
| | **United States** | **266** | | **United States** | **824** |

Source: U.S. Census Bureau
http://www.census.gov/compendia/statab/health_nutrition/health_care_resources/

Indiana's health care service provision ranks below the national average (Table 1). Using the number of physicians per capita as an indicator, Indiana ranks 39th among the 50 states. Indiana has only 213 physicians per 100,000 residents and is ranked far below the national average of 266 physicians per 100,000 residents. Massachusetts takes the lead with 450 physicians per 100,000 residents, followed by Maryland and New York State with 411 and 389, respectively. Even when comparing Indiana to other Midwestern states, it still ranks quite low. The deficit of physicians is slightly compensated by an above average number of nurses per capita. With 877 nurses per 100,000 residents, Indiana exceeds the national average of 824 nurses per 100,000 residents and ranks 25th among U.S. states.

Taking a closer look inside Indiana reveals stark disparities across the 92 counties. On average, there are 99 physicians per 100,000 county residents, and 50% of the counties have fewer than 82 per 100,000. With 306 physicians per 100,000 residents, Marion County (Indianapolis) has the highest number of physicians per capita, followed by Vanderburgh County (Evansville) with 289 physicians per 100,000. At the other end of the spectrum are small, predominantly rural counties with as few as only seven physicians per 100,000 residents. It is thus not surprising that the vast majority of a recent survey in rural Indiana rated the lack of rural health care and health services as a top priority for State Government (PCRD 2006).

Within Indiana, the number of physicians per county resident is positively correlated with the county's population size ($r$ = 0.654). Positive correlations with population size are also found when zooming in on the main specialty areas (Table 2). Moreover, the correlation coefficients between specialty areas are all significantly positive, suggesting a pattern of co-location and agglomeration.

**Table 2**. Correlation Coefficients among Population Size and Rate of Physicians per Residents for Selected Specialties, n=92 Counties

| | Population 2003 | Total Physicians | Primary Care | Emergency Medicine | Internal Medicine | Ob / Gyn | Psychiatry | Surgery (Gen. & Sub.) |
|---|---|---|---|---|---|---|---|---|
| Population 2003 | 1.000 | | | | | | | |
| Total Physicians | 0.654 | 1.000 | | | | | | |
| Primary Care | 0.331 | 0.739 | 1.000 | | | | | |
| Emergency Medicine | 0.185 | 0.481 | 0.279 | 1.000 | | | | |
| Internal Medicine | 0.754 | 0.878 | 0.529 | 0.334 | 1.000 | | | |
| Ob/Gyn | 0.456 | 0.705 | 0.465 | 0.426 | 0.485 | 1.000 | | |
| Psychiatry | 0.352 | 0.704 | 0.410 | 0.255 | 0.555 | 0.406 | 1.000 | |
| Surgery (Gen. & Sub.) | 0.627 | 0.896 | 0.523 | 0.398 | 0.787 | 0.682 | 0.622 | 1.000 |

The bias towards the most urban centers is visualized in Figure 3. It portrays the cumulative distribution of physicians relative to the cumulative population distribution of the 92 counties after sorting counties in ascending order by population size. The curves for each specialty area are below the $45^{o}$ line, suggesting that the smaller counties receive a disproportionately small share of the physicians. The disparities are least pronounced for primary care and emergency medicine. They are, however, quite pronounced for internal medicine: almost 39% of all internists are located in the largest county, Marion County. These patterns suggest that Indiana's mixture of urban and rural counties sets the stage for an inequitable provision of health care services with health care professionals being disproportionately located in urban centers. Under these conditions, rural areas are prime candidates for lack of access to health care resources which may result in delayed treatment and poor health outcomes as possible consequences.

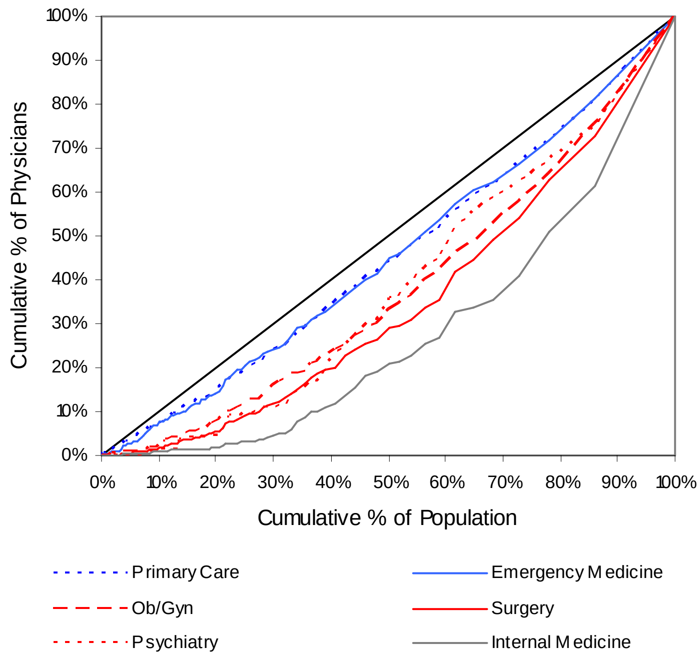


**Figure 3**. Cumulative Distribution of Physicians relative to the Cumulative Population Distribution across Indiana Counties, 2003

For primary care, the Indiana State Department of Health identified 16 counties that are entirely designated as federal primary care shortage areas and 15 counties that are partially designated as primary care shortage areas (Indiana Health Care Professional Development Commission 2001). For all physicians in 2003, Figure 4 shows the spatial distribution of physician-to-population ratios across Indiana counties. Counties along the Indiana-Illinois border have particularly low physician-to-population ratios whereas the major urban agglomeration around Indianapolis has the largest. Table 3 lists the counties with the lowest physician-to-population ratios.

**Table 3:** Physician to Population Ratio for inadequately served Indiana Counties

| County | Number of physicians | Population | Physician to population ratio |
|---|---|---|---|
| Ripley | 4 | 26,523 | 1-to-6,631 |
| Ohio | 1 | 5,623 | 1-to-5,623 |
| Vermillion | 3 | 16,788 | 1-to-5,596 |
| Newton | 3 | 14,566 | 1-to-4,855 |
| Posey | 7 | 27,061 | 1-to-3,866 |
| Crawford | 3 | 10,743 | 1-to-3,581 |
| Lagrange | 10 | 34,909 | 1-to-3,491 |
| Owen | 7 | 21,786 | 1-to-3,112 |
| Pike | 5 | 12,837 | 1-to-2,567 |
| Union | 3 | 7,349 | 1-to-2,450 |
| Switzerland | 4 | 9,065 | 1-to-2,266 |
| Spencer | 9 | 20,391 | 1-to-2,266 |
| Sullivan | 10 | 21,751 | 1-to-2,175 |
| Warren | 4 | 8,419 | 1-to-2,105 |
| Adams | 16 | 33,625 | 1-to-2,102 |
| Martin | 5 | 10,369 | 1-to-2,074 |

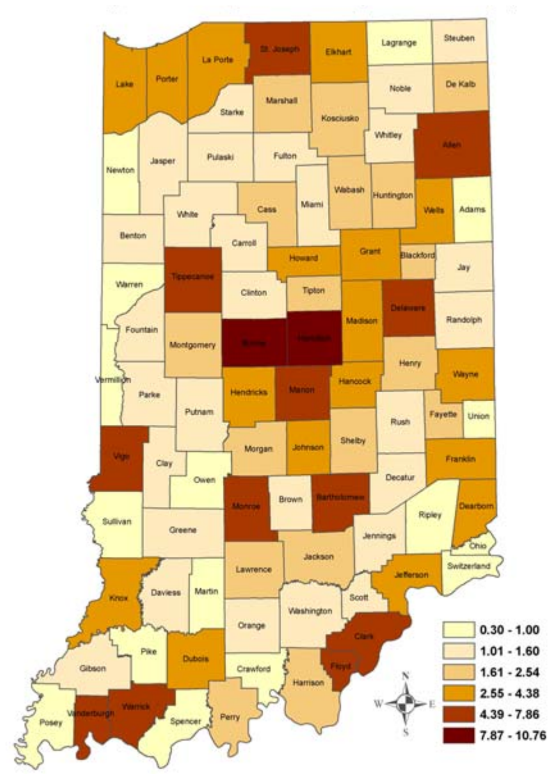


**Figure 4:** Physicians-to- population in Indiana Counties, 2003 [expressed per 2,000)

***Data***

Data for this analysis –including the population in each county, geographic coordinates of cities and county centroids, number of physicians in each county, health facilities location and number of beds, distance between population and health facilities– were collected from a number of different sources. The population data were extracted from the US Census Bureau (2000 Census Summary File 1). Geographic centers of places and each county were created using ET Geo Wizards tools for ArcGIS. The number of physicians was derived from STATS Indiana, the web-based information center of the Indiana Business Research Center (IBRC), a division of Indiana University’s Kelley School of Business. Finally, data about health care service location (hospitals and rural health clinics) and number of beds were obtained from health care providers’ directory of Indiana State Department of Health. All health care facilities were geo-coded using their street addresses.

For the county population, street addresses were not available and thus requires a spatial aggregation of the population. Since the population is not uniformly distributed within the county, the use of geographic centroids is not an appropriate representative of population location and potentially generates substantial errors in distance calculations.

To reduce potential errors, county residents are assigned to three different locations (see Figure 5):

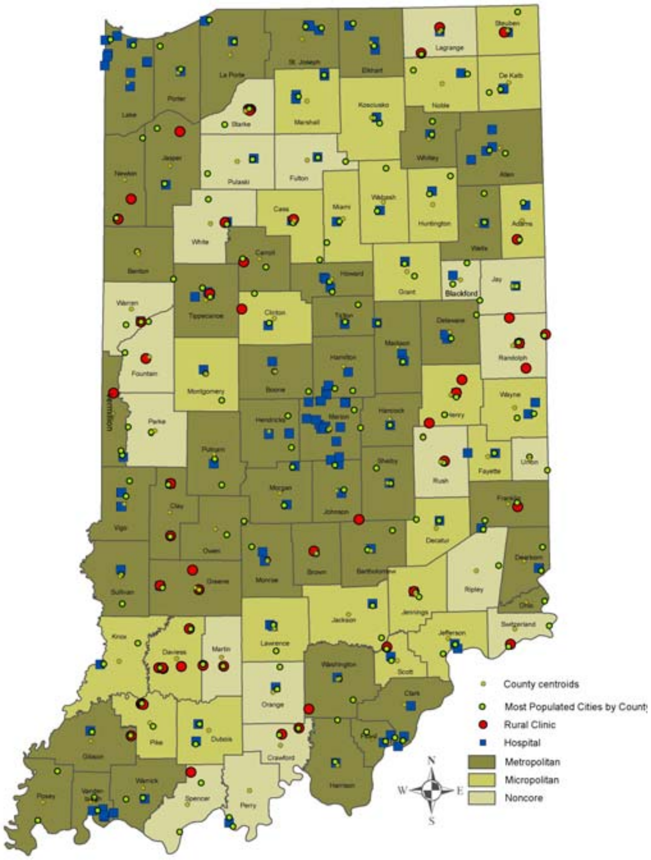


**Figure 5:** Population Points and Health Care Service Locations in Indiana

- residents of the largest city in the county are assigned the mid point of the largest city;
- residents of the second largest city in the county are assigned the midpoint of the second largest city;
- all other county residents are assumed to be uniformly distributed across the county and their average location is assumed to be the county midpoint.

Straight-line distances between population centers as defined above, and street addresses of health care providers were derived by using Hawths analysis tools for ArcGIS. Table 4 shows the design of the data matrix. Note that there are three entries for each county corresponding to the internal distribution of the population within counties.

**Table 4:** Design of the Data Matrix

| County | Geo-reference | Population Center | Population | Distance to Hospitals [km] | | | |
|---|---|---|---|---|---|---|---|
| | | | | Hospital 1 | Hospital 2 | … | Hospital *n* |
| Adams | Largest City | Decatur | 9,528 | 230 | 230 | … | 210 |
| | 2nd largest city | Berne | 4,150 | 236 | 236 | … | 216 |
| | Rest of the County | County Midpoint | 19,947 | 233 | 233 | … | 213 |
| … | | … | … | … | … | … | … |
| Whitley | Largest City | Tri-Lakes | 3,925 | 173 | 173 | … | 152 |
| | 2nd largest city | Columbia | 7,077 | 174 | 175 | … | 154 |
| | Rest of the County | County Midpoint | 19,705 | 174 | 174 | … | 153 |

### *Measuring Spatial Accessibility Using a Gravity-based Method*

It is assumed that all residents can utilize all healthcare services in the state. However, services in close proximity are more valuable to users than those further away. Also, services in a highly populated area are effectively less available than those with less heavily populated ones due to the proximity of large demand in close proximity. This rationale gives rise to a gravity-based measure of accessibility and nicely combines travel impedance, supply, and demand. Its ease of computation, light data requirements, and its sensitivity to even slight changes in input data make it ideal suited to track changes in accessibility over time and to use it as a tool for evaluating changes in health care delivery.[4]

The demand-adjusted gravity measures are specified for each county $i$ = 1, …, 92. In each county $i$, the population, $P$, is assumed to live at one of three locations $i(1)$, $i(2)$ and $i(3)$ that correspond to the midpoints of the largest city, second-largest city and the county. The capacity of health care services $j$ = 1, …, $n$ is denoted by $S_j$, and the distance between the population at $i(k)$ and health care service $j$ is denoted by $d_{i(k)j}$. Thus, demand-adjusted accessibility in county $i$, $A_i$, takes on the form:

$$A_i = \sum_{j=1}^{n} \frac{\sum_{k=1}^{3} P_{i(k)} S_j d_{i(k)j}^{-\beta}}{V_j}$$

where the demand at service location $j$, $V_j$, is defined as:

$$V_j = \sum_{i=1}^{92} \sum_{k=1}^{3} P_{i(k)} d_{i(k)j}^{-\beta} .$$

Travel impedance is operationalized as $\beta = 1$. Moreover, two types of services are specified. The first type refers to hospitals and rural health clinics, with capacity being proxied by the number of hospital beds,[5] thus making $A_i$ a measure of access to hospital care. The second type refers to physicians. However, data on exact physician service location are not available; thus, it is assumed that the county's total number of physicians is spatially allocated to the county's hospitals such that the allocated physician's share equals the share of hospital beds at that location.[6]

Since there is no natural unit for demand-adjusted accessibility, a meaningful comparison between different specifications of the accessibility measure and across policy scenarios is difficult. To address this issue, the accessibility measures defined above are

[4] In that regard, it is certainly superior to the designation of HPSAs which are threshold based and do not allow a fine differentiation of accessibility and its changes over time.

[5] More precisely, we chose the "number of hospital beds + 1" since rural health care clinics do not have hospital beds.

[6] Not surprisingly, this artificial assignment of physician locations to hospital locations implies a strong correlation between the two specifications of accessibility ($r$ = 0.899).

transformed into measures of *relative* accessibility, *RA*. The transformation is a re-scaling of the accessibility values, $A_i$, onto a scale from 0 to 1:

$$RA_i = \frac{A_i - \min\limits_{i=1,\ldots,92} A_i}{\max\limits_{i=1,\ldots,92} A_i - \min\limits_{i=1,\ldots,92} A_i}$$

The county with RA=1 has the highest health care accessibility among the 92 counties and the county with RA=0 has the lowest.

### *Empirical Results*

This section begins with a description of spatial variations in health care accessibility, followed by sub-sections on important correlates of health care accessibility, and the identification of population characteristics in counties with varying levels of health care accessibility. It concludes with a demonstration of how the gravity measures can be used to evaluate the effects on health care accessibility.

*Spatial Variations in Health Care Accessibility across Indiana Counties*

As shown in Figures 6 and 7, counties in and around the Indianapolis-Carmel Metropolitan Statistical Area in the center of the state as well as some regional centers enjoy good access to both hospital care and physician care. In contrast, there are clusters of counties, especially in the more peripheral areas along the borders to Illinois, Kentucky and Ohio, where access to health care is exceptionally poor.

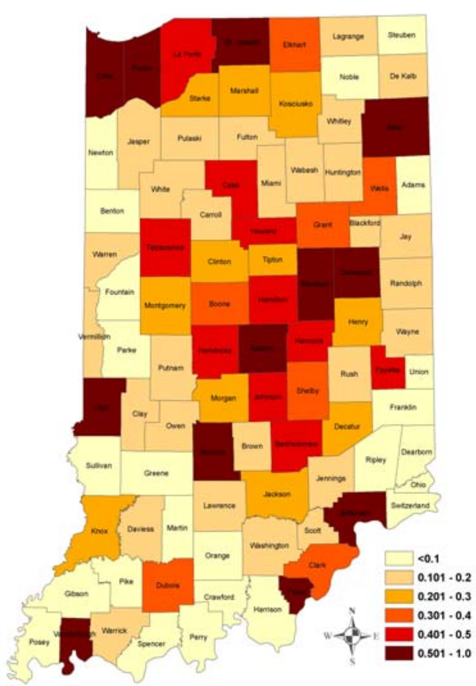


**Figure 6.** Accessibility to Hospital Care in Indiana Counties (0 = lowest, 1 = highest)

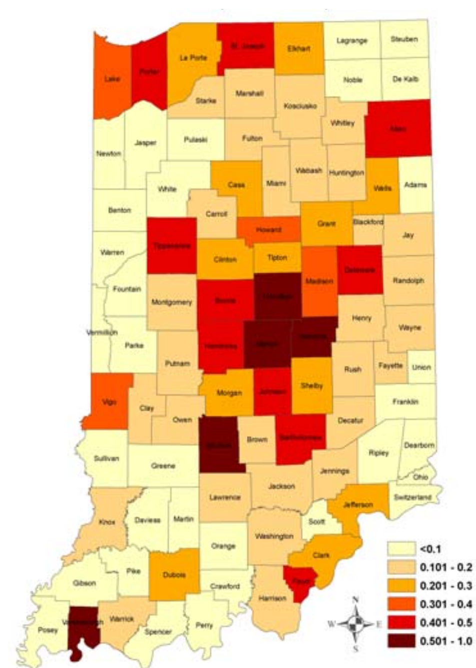


**Figure 7.** Accessibility to Physician Care in Indiana Counties (0 = lowest, 1 = highest)

However, remarkable are also the differences in accessibility to hospital versus physician care. As can be expected, good accessibility to hospital care is strongly concentrated in the regional centers. Marion County with its abundance of hospital beds ranks first, followed by large urban counties that serve as regional centers. As shown in Table 5, they include Allen County (Fort Wayne), Lake County (Gary), Vigo County (Terre Haute), Madison County (Anderson), Jefferson County (New Albany), Monroe County (Bloomington) and Porter County (Portage, Valparaiso), as well as Vanderburgh County (Evansville).

**Table 5**: Top-Ten Counties in Indiana with the Best Access to Hospital Care

| Rank | County | Hospital Access | Rank | County | Physician Access |
|---|---|---|---|---|---|
| 1 | Marion | 1.000 | 1 | Marion | 1.000 |
| 2 | Vanderburgh | 0.936 | 2 | Vanderburgh | 0.637 |
| 3 | Vigo | 0.706 | 3 | Hamilton | 0.632 |
| 4 | Jefferson | 0.662 | 4 | Monroe | 0.538 |
| 5 | Allen | 0.640 | 5 | Hancock | 0.525 |
| 6 | Lake | 0.628 | 6 | St. Joseph | 0.500 |
| 7 | St. Joseph | 0.550 | 7 | Allen | 0.482 |
| 8 | Madison | 0.541 | 8 | Boone | 0.466 |
| 9 | Monroe | 0.536 | 9 | Hendricks | 0.462 |
| 10 | Porter | 0.517 | 10 | Tippecanoe | 0.455 |

Twenty-three of the 31 counties along the Ohio, Kentucky and Illinois border have relatively poor access to hospital care with accessibility scores not exceeding 0.2. For the ten counties with the poorest hospital accessibility (Table 6), accessibility is even smaller than 0.055 and thus almost 20 times poorer than that of Marion County, the county with the highest hospital care accessibility. Geographically, the greatest concentration of poor hospital care accessibility is situated in the southern part of Indiana. Six of those counties are located along the Ohio River.

**Table 6:** Bottom-Ten Counties in Indiana with the Least Access to Health Care

| Rank | County | Hospital Access | Rank | County | Physician Access |
|---|---|---|---|---|---|
| 1 | Ohio | 0.000 | 1 | Posey | 0.000 |
| 2 | Switzerland | 0.001 | 2 | Switzerland | 0.005 |
| 3 | Posey | 0.001 | 3 | Ohio | 0.010 |
| 4 | Perry | 0.006 | 4 | Perry | 0.018 |
| 5 | Spencer | 0.006 | 5 | Spencer | 0.018 |
| 6 | Crawford | 0.009 | 6 | Crawford | 0.018 |
| 7 | Franklin | 0.047 | 7 | Newton | 0.037 |
| 8 | Benton | 0.047 | 8 | Sullivan | 0.046 |
| 9 | Martin | 0.049 | 9 | Benton | 0.048 |
| 10 | Pike | 0.053 | 10 | Ripley | 0.051 |

The spatial distribution of accessibility to physician care also reveals a stark contrast between the more urban areas with good accessibility, especially in the center of the state around Indianapolis, and the more rural counties with poor accessibility. However, unlike in the case of hospital accessibility, favorable access to physicians is not only characteristic for urban counties that serve as regional centers (Vanderburgh County and Allen County) but also for the two counties housing Indiana's major universities (Tippecanoe and Monroe counties), and the fast growing suburban counties of Indianapolis (Boone, Hamilton, Hancock, and Hendricks counties). Posey County in Southern Indiana has the worst access to physicians, followed by four other counties located along the Ohio River, namely Switzerland, Ohio, Perry, and Spencer counties. Only two of the bottom-ten counties with poor physician accessibility, Benton and Newton counties, are located in the northern portion of the state. They are part of a vast area along the Illinois border that has also been identified as a Health Professional Shortage Area according to the criteria of the Department of Health and Human Services.

The core-periphery disparity in health care accessibility is further confirmed by a strong negative association between accessibility and rurality. When measuring rurality via the index of relative rurality[7] (Waldorf 2006), the correlation indices are significantly negative (r = -0.841 for hospital care and r = -0.830 for physician care) and, as visualized in Figure 8, the decline in accessibility to health care with increasing rurality is quite pronounced.

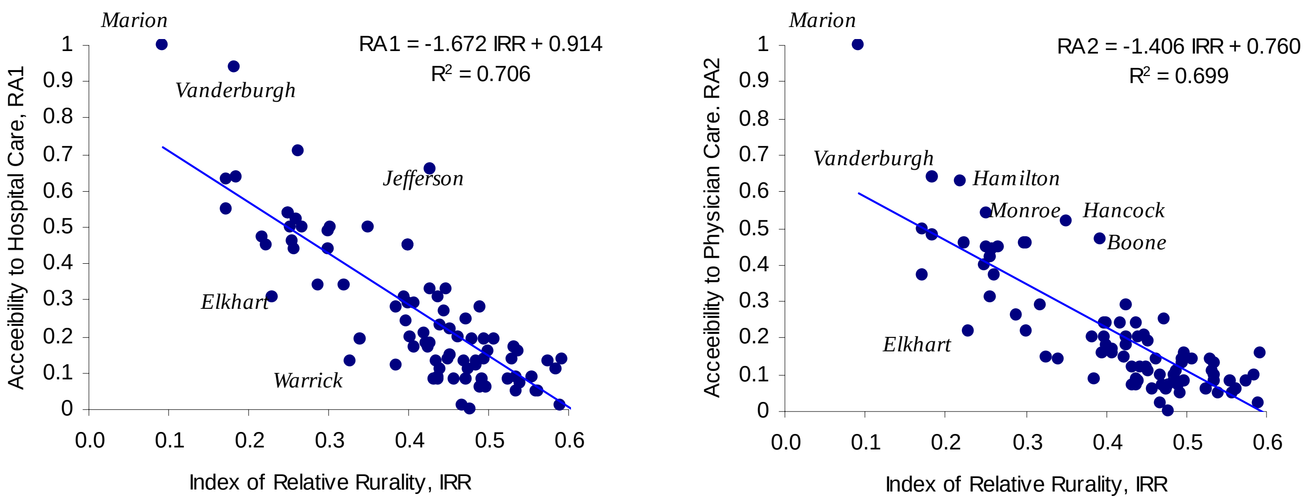


**Figure 8**: Relationship between Health Care Accessibility and Rurality

[7] The index of relative rurality is based on four variables: population density (log), population size (log), % urban, straight-line distance to the closest to Metropolitan Statistical Area. Each variable is re-scaled from 0 to 1, and the unweighted average of the rescaled variables is chosen as a link function synthesizing the contributions of the four the individual variables (Waldorf 2007).The index of rurality is a continuous measure of rurality that varies from 0 (most urban) to 1 (most rural). Among Indiana counties, most urban county (Marion County) has an index of 0.09 and for the most rural counties the rurality index is slightly less than of 0.6.

Interestingly, this strong negative link between accessibility and rurality persists even when accounting for socio-economic county characteristics. In a multivariate context that includes rurality, education, ethnic mix, and the shares of elderly and uninsured, the percentage of college-educated residents is the only variable aside from rurality that has a significant co-variation with accessibility to health care. Table 7 reports the multivariate regression results for accessibility to both hospital care and physician care. In both cases, the index of relative rurality is estimated to have a negative effect and accounts for the bulk of variation in accessibility. Its negative effect on hospital care is, however, substantially more pronounced than its negative effect on physician care, thereby reflecting hospital's particularly strong locational bias towards regional centers. The effect of education on accessibility is more pronounced for physician care than hospital care, and reflects the tendency of physicians to be over-represented in college towns and suburban communities.

**Table 7**. Covariates of Accessibility to Health Care

| Variable | Hospital Care | | Physician Care | |
|---|---|---|---|---|
| | b | t | b | t |
| Intercept | 0.588 | 2.078 | 0.327 | 1.544 |
| Index of Relative Rurality | -1.272 | -9.295 | -0.855 | -8.354 |
| Percentage of College-educated Residents | 0.007 | 2.254 | 0.011 | 4.612 |
| Percentage of Hispanic Residents | 0.000 | 0.019 | -0.002 | -0.522 |
| Percentage of Uninsured Residents | 0.003 | 0.394 | 0.001 | 0.137 |
| Percentage of Elderly Residents (age 55+) | 0.008 | 1.197 | 0.003 | 0.612 |
| Medium Household Income | -0.003 | -1.091 | 0.000 | 0.070 |
| Adjusted R Square | 0.712 | | 0.775 | |
| n | 92 | | 92 | |

*County Classification by Health Care Services Accessibility*

One of the main goals of public health care systems is to provide equitable accessibility of health care services according to the need for care.. Although health care is a public good, the analysis so far has shown that it is not equally available at all places, with some counties suffering from both poor access to hospital care and poor access to physician care. This section identifies and characterizes the counties that are most severely in need of improved access to health care.

Towards that end, accessibility to hospital care and accessibility to physician care are combined and a three-way classification based on median and average values of accessibility is suggested. Since the distribution of both accessibility measures is highly skewed, the averages exceed the medians, and counties with below-median accessibility score for *both* hospital and physician care are categorized as counties with poor health care access. Counties with good access to health care are defined as counties that have above average accessibility to both hospital and physician care. Finally, counties not falling into either of the two categories defined above, are classified as counties with medium access to health care (Figure 9).

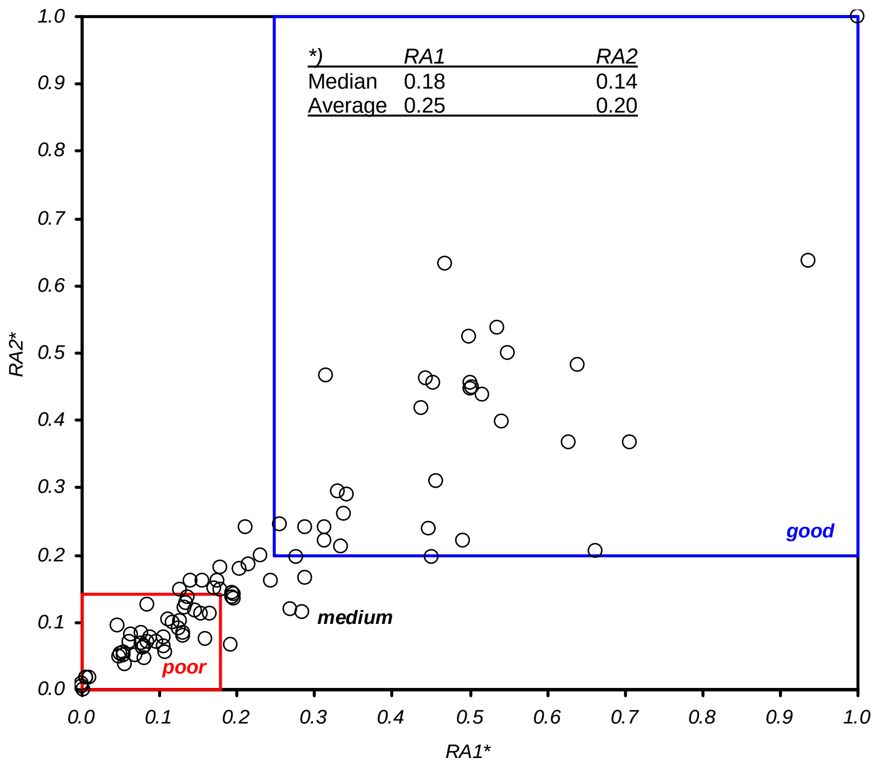


**Figure 9:** Classification of Counties along RA1 (Hospital Care) and RA2 (Physician Care)

In total, 40 or 44% of Indiana's 92 counties are poor-access counties whereas only 30 of Indiana counties have good access to health care. The remaining 22 counties are categorized as medium-access counties. Figure 10, which maps their distribution, clearly indicates health care services are not equally distributed across Indiana. People living in and around the Indianapolis-Carmel Metropolitan Statistical Area, along Lake Michigan in the North, in regional centers, or in counties housing colleges and universities generally have good access to health care services. Policy makers do, however, need to be concerned with the accessibility in the more rural counties along the Illinois border and along the Ohio River. It is in those counties that the results unequivocally unearth insufficient health care provision.

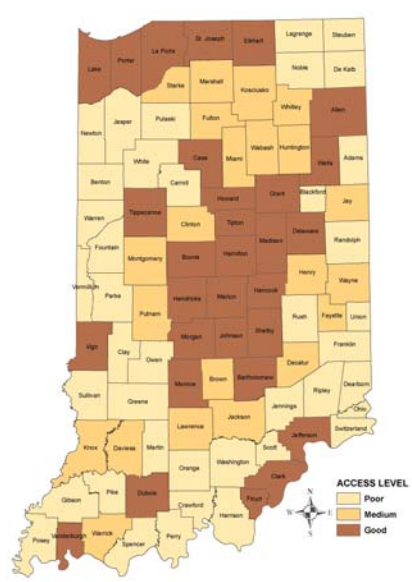


**Figure 10:** Access to Health Care

Table 10 summarizes the characteristics of the three types of counties. The poor access counties tend to be smaller in size and substantially more rural than the medium-access and high-access counties. In total, the poor-access counties house 905,875 residents, or 14.9% of Indiana residents. While 71.5% of Indiana population lives in good-access counties, 13.6% of population locates in medium access counties.

Poor-access counties have a disproportional share of some of the most vulnerable population segments. That is, they have, on average, higher proportions of elderly, children, and poorly educated residents. In fact, educational attainment levels contribute strongly to the dissimilarities across the three types of counties. While, on average, the percent of the population with low educational attainment (without high school degree) is greater in poor access counties, good access counties have a greater percentage of well-educated residents. The percent of residents with at least Bachelor's degree is almost two times higher in good compared to poor health care areas.

Counties with good access to health care have, on average, a higher median household income. The median household income difference between good and poor health care access areas is more than $5,000. Yet, with regard to poverty levels, there is barely any difference between the three types of counties, hovering around 8.5%. In combination, the information on household income and poverty suggests that the counties with good access to health care are characterized by a stronger inequality, matching the information on their proportionally having higher representations of ethnic and racial minorities.

**Table 10:** Characteristics of Indiana Counties by Health Care Accessibility Type

| Characteristic | Poor (n=40) | | Medium (n=22) | | Good (n=30) | |
|---|---|---|---|---|---|---|
| | Average | Std.Dev | Average | Std.Dev | Average | Std.Dev |
| Total Population | 22,647 | 10,329 | 37,537 | 14,850 | 144,960 | 166,945 |
| % Children (0 to 17 yrs) | 26.76 | 2.05 | 25.79 | 1.63 | 25.73 | 2.55 |
| % Elderly ( 65+) | 13.16 | 1.66 | 13.90 | 1.35 | 11.93 | 1.94 |
| % Adults with at least Bachelor's Degree | 11.37 | 1.98 | 13.12 | 3.25 | 22.36 | 8.33 |
| % Adults without a High School Degree | 21.03 | 4.90 | 19.52 | 4.05 | 16.88 | 3.93 |
| % Hispanic | 1.65 | 1.42 | 2.10 | 1.82 | 4.19 | 2.65 |
| % Black | 0.52 | 0.77 | 1.81 | 1.23 | 11.29 | 6.34 |
| % Population in Poverty | 8.38 | 1.90 | 8.37 | 2.07 | 8.84 | 2.61 |
| Median HH Income ($) | 40,117 | 4,199 | 40,823 | 4,321 | 45,352 | 8,759 |
| Index of Relative Rurality | 0.48 | 0.06 | 0.41 | 0.05 | 0.29 | 0.08 |

*Policy Simulations*

Providing equal provision of healthcare services for all people in all parts of Indiana is a challenge to policymakers. One problem in establishing an equitable health care system is providing resources in locations that are close enough to be reached with a reasonable amount of effort by the populations being served (Wang and Luo 2005). For several decades, the physical distance between the provider and the consumer has been recognized as an important barrier to care and studies have shown that most people will not travel far distances for basic preventive and curative care (Perry and Gesler 2000).

Thus, ensuring spatial accessibility or the potential for provider/consumer links is a key objective for regional and public health planning. This is a difficult objective from a spatial point of view since agglomeration and economies of scale and scope support the development of health services in urban areas.

In Indiana, the average straight line distance to the nearest health facility is 3.87 miles. The red dots in Figure 11 show the locations within circles with radii of 3.87 miles from health care facilities. Large portions of Indiana fall outside those circles. Overall, 59.6 percent or 3,623,913 of Indiana residents live within a distance of 3.87 miles from health care services. However, for the rural population this is true for only 8 percent or 290,301 residents. This suggests social imbalances in the spatial allocation of health care providers that are epitomized in a crass rural-urban disparity.

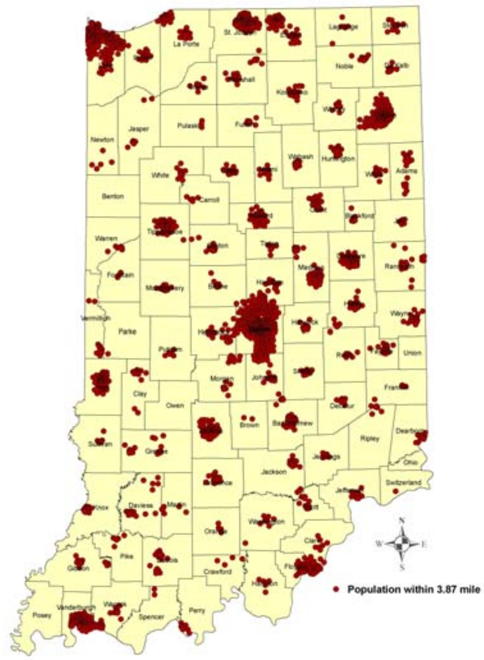


**Figure 11.** Locations within 3.87 Miles from Health Care Services

This result is echoed by the National Rural Health Association (2006), suggesting that rural residents have greater difficulty reaching health care providers because of long travel distances and travel times. In the case of acute care, long distances to hospitals may be the deciding factor between life and death. More generally, poor physical accessibility to health care services reduces the use of services and leads to poorer health outcomes (Lovett et al. 2002). In this regard, Rural Health Clinics (RHCs) take on a pivotal role. RHCs are located in areas designated by the Bureau of the Census as rural *and* by the Secretary of the Department of Health and Human Services *or* the State as medically underserved, a geographic HPSA or a population group of HPSA[8]. Rural Health Clinics act as the first point of contact for patients. They provide first response emergency care, routine diagnostic and laboratory services, and establish arrangements with providers and suppliers to furnish medically necessary services not available at the clinic. Therefore, closing rural health clinics or reducing their range of services will extend the medically underserved areas even further, and increase the population with poor health care access.

The scenarios outlined below thus focus on three policies that are likely to impact spatial accessibility of health care in rural areas. The first policy scenario examines closure of rural health clinics located within 10 miles from a hospital. The second scenario evaluates closure of remote rural clinics and the third scenario analyses increases in the service capacity in three regional centers.

[8] Fact Sheet: Rural Health Clinic (available from: [http://www.cms.hhs.gov/MLNProducts/downloads/2006rhc.pdf](http://www.cms.hhs.gov/MLNProducts/downloads/2006rhc.pdf)) Accessed: April 3, 2007

*Scenario 1: Closure of rural health clinics located within 10 miles from a hospital*

This policy simulation mirrors current trends in hospital consolidation. Many large health systems are consolidating their practices to take advantage of economies of scale and scope. As a result smaller clinics are being closed and patients are referred to larger, full service hospitals or health clinics. In this scenario, rural health clinics within a 10-mile range from a full-service hospital are eliminated. In total 27 of the 55 rural health clinics are affected. They are mostly located in counties with poor and medium health care access such as Clay, White, Randolph, Rush, Lagrange, Jennings, Starke and Daviess counties

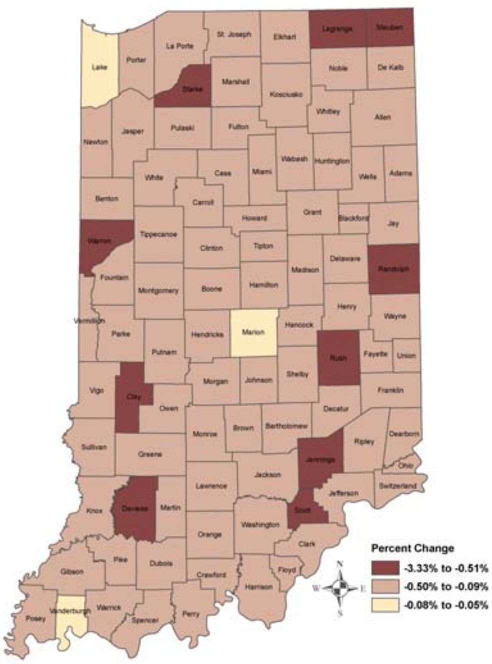


**Figure 12.** Scenario 1: Percent Change in Accessibility to Hospital Care

Closure of the 27 rural health clinics implies a reduction in health care services, thus negatively affecting spatial accessibility for everybody (Figure 12). As expected, the more urbanized counties such as Lake, Marion, Vanderburgh counties and their surrounding counties are barely impacted by the closures. However, accessibility to hospital care becomes more difficult for people living in sparsely settled, isolated rural communities.

*Scenario 2: Closure of rural health clinics more than 15 miles away from a hospital*

In order to operate, rural health clinics must employ at least one nurse practitioner, physician assistant or certified nurse who is available to provide services at least 50 percent of the time the clinic is open. Rural health clinics must also have a physician present at least once every two week.[9] In this scenario, it is assumed that rural health clinics, whose contracting physicians live too far away, will not be efficient if the clinics are more than 15 miles away from hospitals. In Indiana, 18.2 percent of rural clinics (10 of 55) are more than 15 miles away from full-service hospitals. These clinics are usually located in low density areas including Martin, Brown, Daviess and Clay counties, and more remote counties along the state borders including Vermillion, Switzerland,

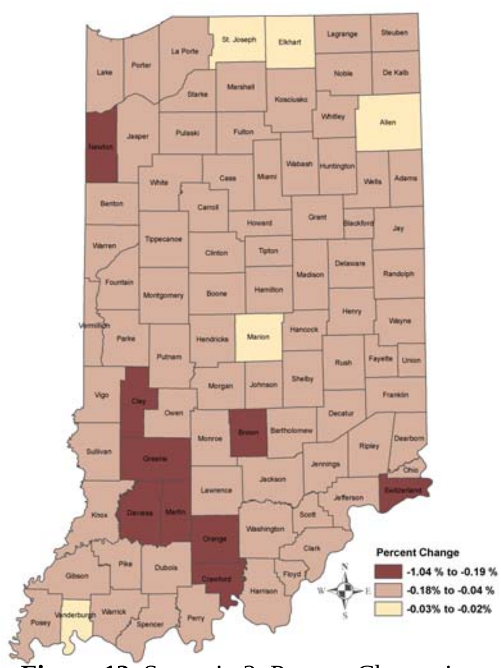


**Figure 13.** Scenario 2: Percent Change in Accessibility to Hospital Care

[9] Office of Community and Rural Health, *What is a Rural Health Clinic?*, Washington State Department of Health (available from: http://www5.doh.wa.gov/hsqa/ocrh/RHC/rhcMminpg.htm)

Newton, and Crawford counties.

As in the first scenario, the closures imply a reduction of overall services and thus all counties are negatively affected. Figure 13 shows that counties that serve as regional centers, such as Vanderburgh County (Evansville) and Allen County (Fort Wayne) respond are least impacted. Yet, the negative impacts on accessibility are clustered in the southwestern portion of Indiana, stretching from Clay County to Crawford County at the Ohio River.

*Scenario 3: Increase in the capacity of hospitals in three regional centers*
This scenario examines what happens if the capacity of existing hospitals is increased. With the move to consolidating hospital services this scenario is also indicative of what we see occurring in health care provision in Indiana. In general, it is known that capacity constraints have an effect on both service quality and patient satisfaction. Today, many hospitals are experiencing severe capacity challenges that range from a lack of available beds to exceedingly long waiting periods for emergency room patients[10]. Increased access (through increase capacity) to hospital care will improve the health status for some of the population.

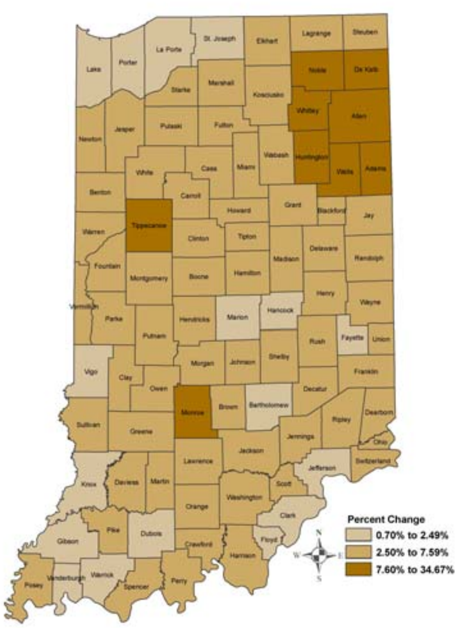


**Figure 14.** Scenario 3: Percent Change in Accessibility to Hospital Care

Figure 14 illustrates the effects of 50% increases in the number of hospital beds located in three regional centers: Monroe County (Bloomington), Tippecanoe County (Lafayette), and Allen County (Fort Wayne). This policy affects only 12 of the 159 full-service hospitals and the effects on hospital accessibility are quite varied, with increases in relative accessibility ranging from 0.7% to 34.7%. Not surprisingly, the three regional centers directly affected by the capacity increase gain the most. In contrast, the more remote counties in southern Indiana (including Clark, Floyd, Warrick, and Gibson) only benefit marginally. Interesting is also that the accessibility in Allen County's collar counties is substantially improved, whereas the influence in the immediate neighborhoods of Marion and Tippecanoe counties is much more limited.

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[10] Hospital Capacity Management & Patient Management Information from Accenture (available from: http://www.accenture.com/Global/Services/By_Industry/Health_and_Life_Sciences/Providers/R_and_I/PatientServices.htm)

## Summary and Future Work

This paper demonstrates the utility of the gravity measures as a tool to assess spatial accessibility to health services. The gravity measures presented in this study account for three factors: distances between the population and health care providers; the capacity of health care providers, and the demand for health care. The empirical application indicates that access to health care varies sharply across Indiana counties, with deep pockets of deprived access. While the population in centrally located and urban areas enjoys better access, rural counties in southern Indiana and along the Illinois border have the poorest access to health care. In general, compared to counties with good health care access, the population in counties with poor access to healthcare is predominantly white, poorly educated, and rural, with an above average share of older residents and children. In particular, our results show that more than one third of Indiana citizens do not have reasonable access to health care services, and that rural residents are particularly disadvantaged.

The paper also demonstrates that the accessibility measures can be used for evaluations of health care policies. Our examples show that changes in the provision of health care services –such as closures of rural health clinics or capacity increases– potentially have spatially very differentiated accessibility outcomes. Thus the technique presented in this paper may not only help health care policy makers and planning authorities to identify and target areas and population groups with insufficient access to physician and hospital care but also avoid policy-induced deepening of already existing accessibility disparities.

This research has several limitations that should be addressed in future research. First, the design does not take edge effects into account. Edge effects occur when the study area is defined by a border but possible border crossings are ignored. In this research, the metropolitan core counties of the Chicago, Louisville, and Cincinnati metropolitan areas in fact offer a host of health care services that may induce Indiana residents to travel across state borders for medical care. The second limitation is the issue of spatial scale and the associated modifiable areal unit problem. The use of small areal units has a tendency to yield unreliable rates due to a small population at-risk. Large areal units, on the other hand, ignore internal variations and thus hide important nuances within an area (Nakaya 2000). Third, the specification of the gravity measure ignores asymmetries in travel behavior. That is, it assumes equal probabilities that residents of a large city will travel to a hospital in a rural area and that a rural resident will travel to a similar hospital in an urban area. This symmetry implies that "intervening opportunities" which are typically much more numerous for urban compared to rural dwellers, are ignored. Finally, the measures can be refined by improving the geo-referencing of the population as well as the physicians, and by disaggregating by type of health care services and population characteristics. The differentiation by population attributes will be particularly important when integrating spatial accessibility with the social constraints of health care utilization (Wang and Luo 2005).

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